Renewable and Sustainable Energy Reviews 29 (2014) 463–472

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The HIGH-COMBI project: High solar fraction heating and cooling systems with combination of innovative components and methods

Vassiliki N. Drosou [a,*], Panagiotis D. Tsekouras [b], Th.I. Oikonomou [a], Panos I. Kosmopoulos [c], Constantine S. Karytsas [d]

[a] Centre for Renewable Energy Sources and Saving, Solar Thermal Systems Department, 19th km Marathon Avenue, Pikermi, 19009 Athens, Greece
[b] National Technical University of Athens, School of Mechanical Engineering, Laboratory of Solar Energy, Heroon Polytechniou 9, Zografou Campus, 15780 Athens, Greece
[c] Laboratory of Environmental and Energy Design of Buildings and Settlements, Democritus University of Thrace, Department of Environmental Engineering, Vas Sofias 12, Xanthi, Greece
[d] Centre for Renewable Energy Sources and Saving, Geothermal Energy Department, 19th km Marathon Avenue, Pikermi, 19009 Athens, Greece

ARTICLE INFO

Article history:
Received 17 October 2012
Received in revised form
2 August 2013
Accepted 11 August 2013
Available online 23 September 2013

Keywords:
Solar thermal systems
Solar cooling
High solar fraction
Seasonal storage
Solar heat pump
Absorption cooling

ABSTRACT

The scope of the HIGH-COMBI project is the development of high solar fraction systems by innovative combination of optimized solar heating, cooling and storage technologies as well as control strategies, in order to contribute and assist the further deployment of the solar energy market. Within this project, six demonstration plants were installed in four European countries (Greece, Italy, Spain and Austria). The purpose of this article is to assess the result achieved in the technical field of the project and to present the technical aspects of the six innovative demonstration systems realised during the project period.

Contents

Abbreviations: ACM, absorption cooling machine; AHU, air handling unit; BTES, borehole thermal energy storage; CHP, combined heat and power plant; COP, coefficient of performance; CRES, Centre for Renewable Energy Sources and Saving; CSHPSS, central solar heating plants with seasonal storage; DEC, desiccant evaporative cooling device; DHW, domestic hot water; ESTIF, European Solar Thermal Industry Federation; GHE, ground heat exchangers; HP, heat pump; HVAC, heating–ventilation–air conditioning; IEA, International Energy Agency; RES, renewable energy sources; SAC, solar air conditioning (systems); SF, solar fraction; SPFel, seasonal performance factor (electrical); STES, seasonal thermal energy storage; UNEP, United Nations Environment Program; UTES, underground thermal energy storage

* Corresponding author. Tel.: +30 2106603381; fax: +30 2106603300.
E-mail addresses: drosou@cres.gr (V.N. Drosou), ptsek@central.ntua.gr (P.D. Tsekouras), thoikonomou@cres.gr (Th.I. Oikonomou), pkosmos@env.duth.gr (P.I. Kosmopoulos), kkari@cres.gr (C.S. Karytsas).

1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.08.019

1. Introduction

In 2010, the European Commission adopted the communication “Energy 2020” that defines a new strategy toward 2020 for a competitive, sustainable and secure energy [1]. Priority is given to buildings and transport sectors. Through directives to improve building energy efficiency (energy performance of buildings directive, or EPBD), the European Union has recognized the high potential for energy savings from buildings and promote the installation of solar thermal systems in the building sector.

Solar thermal systems for hot water production are already mandatory in new buildings according to solar ordinances in Spain [2], Portugal [3], Italy [4], Greece [5] and other European Countries [6]. The most common solar energy thermal application is for sanitary hot water (SHW) production [7].

Small systems for SHW production using natural flow systems, known as thermosyphons, are common practice in southern Europe and in general in frost-free climates [8]. Systems combining production of SHW and space heating, known as “solar combi” systems, are well suited to middle and high latitudes, due to significantly higher solar radiation in the transitional periods around winter (September–October and March–May) and the significant heating demand in these latitudes at that time [8]. For this reason, they are popular in central and northern Europe [9]. Installations with large solar collector areas and small size heat storage capacity can cover around 50% of the total heat demand. The percentage can be higher in some cases of large storage capacities and primary energy savings up to 80% can be realised [10,11]. Simulations of central solar heating plants with seasonal storage (CSHPSS) has shown that the solar fraction of such systems varies between 50% and 100% [12]. The heat produced by the collectors may be stored in thermal energy storages in order to provide domestic hot water and space heating when required [13].

The addition of a solar cooling facility makes the system complete, covering all building thermal and cooling demands [11]. These systems are known as “solar combi plus” systems. “Solar combi plus” systems, seem to be proved advantageous since high cooling loads coincide with high solar radiation, and consequently the readily available solar energy from the existing solar collectors can be exploited by a heat driven machine [14]. The use of the solar collectors is thus extended to a whole year, making the system financially attractive, when the number of annual full-load hours is high [15]. Furthermore, since the cooling machine is heat driven, the building electrical loads are reduced and the problems associated with peak power demand during summer are minimized [11]. Depending on the size of solar collector field, hot water storage, local climatic conditions and building loads, a “solar combi plus” system may cover 10–60% of the combined space heating/cooling and SHW demand at southern, central and northern European countries [16].

The HIGH-COMBI project focused on developing innovative high solar fraction systems by optimized combination of solar heating and cooling technologies with adapted seasonal storage device that can reach a solar fraction approaching 100% [17].

This paper presents the six demonstration installations that were constructed in the framework of HIGH-COMBI project. For each installation is given the technical characteristics, the operational principles of summer and winter operation for cooling and heating respectively, as well as available solar fraction indicators [17].

2. Energy related topics of the solar cooling sector

Europe has a well-structured market, serving various solar thermal applications. With almost 2.6 GW_{th} installed in 2011, the total installed capacity in Europe is now 26.3 GW_{th}, generating 18.8 TWh of solar thermal energy while contributing to savings of 13 MMt CO_2 [18].

In an effort to improve the energy performance of buildings and the integration of renewables, the primary goal should always be to first reduce heating and cooling loads [19]. Simply shifting primary energy from fossil fuels and electricity to solar energy may be environmentally sound, but on the other hand it will prove financially prohibitive; energy waste of solar energy is as unacceptable as any other energy source [20]. Implementing proper building and plant design, construction and operation following well established principles, reducing heat losses in winter and heat gains in summer through the building envelope, using energy efficient equipment and technologies, is a practical and mandatory process for any high performance building project [21].

Solar collector efficiency, simply estimated as the delivered heat to incident solar radiation, mainly depends on the solar thermal technology used, the design and the quality of the collector, the technical characteristics of hot water storage and back-up systems, averaging on an annual basis 40–55% for SHW [22]. In similar way, annual average solar utilization (accounting for storage heat losses and waste heat) of 20–25% have been obtained in “combi systems” in Central Europe and 30–35% in Mediterranean countries. Depending on the size of the solar collector field, hot water storage, local climatic conditions and building loads, “solar combi” systems may cover 10–60% of the combined SHW and space heating demand at central and northern European locations. According to Aidonis et al. [23], the simulations for Greece showed that the “solar combi” systems can be combined with the conventional heating systems, giving high energetic results and solar coverage of the total heating load that can reach 40–50%. Similar results have been presented from Argiriou et al. [24] in a simulation of three systems in Northern Greece.

In parallel, solar thermal systems for cooling is an emerging market with a huge growth potential. Specific guidelines and an overview of various applications are reported in Balaras et al. 2006 [25]. Each solar cooling technology has specific characteristics that match the building's HVAC design, loads, and local climatic conditions. A good design must first exploit all available solar radiation and then cover the remaining loads from conventional sources [26].

According to the handbook for planners for solar assisted air conditioning of building, written by Henning [14] and to the design guidelines presented in Balaras et al. [25], proper calculations for collector and storage size depend on the employed solar cooling technology. The use of solar collectors should be maximized by also supplying heat to cover space heating or SHW loads. Hot-water storage may be integrated between the solar collectors and the heat-driven chiller to dampen the fluctuations in the return temperature of the hot water from the chiller. The storage size depends on the application: if cooling loads mainly occur during the day, then a smaller storage will be necessary than when the loads peak in the evening. Heating the hot-water storage by the backup heat source should be strictly avoided. The storage's only function is to store excess heat of the solar system and to make it available when sufficient solar heat is not available.

In Europe, there has been various projects, scoping the further development of solar cooling, including: CLIMASOL "promoting solar air conditioning" [27]; SACE "solar air conditioning in Europe" [28]; SOLAIR "increasing the market implementation of solar air-conditioning systems for small and medium applications in residential and commercial buildings" [29]; SOLCO "removal of non-technological barriers to solar cooling technology across southern European islands" [30] and at international level through the IEA solar heating & cooling (SHC) program, including: Task 25 "solar assisted air-conditioning of buildings" [31] and Task 38 "solar air-conditioning and refrigeration" [32].

Regarding "solar combi plus" even though some installations have been realized in Europe [33], there are still main obstacles ahead. Among others, "drawbacks" for the massive application of such systems are the high initial cost and the lack of knowledge and practical experience in design, control, operation, installation and maintenance. Although the installed systems worldwide are about 200, there are not yet adequate official reviews and testimonials of these systems [34]. Besides the trained technical personnel for such systems is limited, as there has been no specified training program currently established. As a result, the existing engineers and installers are not thoroughly aware of the varying design parameters and there are no significant provisions of technical support in a local level [33]. Research and development in Europe, including the described at this paper European project HIGH-COMBI, are being brought forward with the view to overcome these barriers. The present study contributes to the solution of the above mentioned issues.

3. Overview of HIGH-COMBI project

The HIGH-COMBI project aimed on developing high—even up to 100%, solar fraction systems by combing the two technologies of "solar combi" and "solar cooling" system with innovative seasonal storage device.

The development of these combined systems has many advantages due to the fact that allows the use of solar energy throughout the whole year, endeavoring to increase the primary energy savings in buildings and consequently to contribute and assist the further deployment of the solar energy market. One of the most signature parameters for examining the economic viability of a technology is the operating cost. Solar Combi plus systems have the advantage of minimizing the operating cost in relation to the conventional energy (fuel or electricity) cost [33]. A second advantage is the positive environmental profile of solar combi systems by the mitigation of CO_2 emissions, through the saving of primary energy and electricity [33]. A significant market-oriented advantage of solar combi systems is that they cover three energy functions—(i.e., heating, cooling and domestic hot water—into one single product [33].

The main objectives of the project were

- Identification of configurations of solar plants for heating and cooling applications.
- Computational analysis of the solar plants and optimization procedures using different combination of technologies.
- Realization of the demonstration plants.
- Development of a simple software tool for dimensioning solar systems under the same configurations.
- Monitoring and technology evaluation.
- Dissemination of the activities on national level and Europe-wide.

In the research phase, different configurations were examined and optimized by detailed simulations. Demonstration plants were constructed, using different combination of technologies, components and control strategies. All demo plants achieved high solar fractions values with a sound economy; for some of the plants more than 70% of coverage for the space heating, domestic hot water and cooling loads was reached. Innovative techniques, components and configurations were examined (e.g., new storages, use of rejected heat during cooling, combined heating and cooling control etc.). Demonstration plants' monitoring data was analyzed, the simulation and design tools validated and the plants' performance evaluated. Market analyses were carried out in order to estimate the potential penetration of these systems in the European heating and cooling market. A user friendly simulation software tool was developed for dimensioning and economic analysis for planners.

The most valuable outcome of the project was the design and development of six innovative High Solar Fraction Demonstration Systems in four European countries (Greece, Italy, Spain and Austria). The sectors of implementation are all medium and large building end-users having heating and cooling loads along the year.

All project information is readily accessible and can be viewed on and/or downloaded from the HIGH-COMBI website at www.highcombi.eu

4. HIGH-COMBI demonstration systems

In the framework of HIGH-COMBI project six demonstration plants have been constructed, using different combination of technologies, components and control strategies, as shown in Table 1.

In Table 2, an overview of the technical characteristics of solar thermal collectors and solar cooling application for each HIGH-COMBI installation is given

The demonstration plants were monitored and analyzed. Solar fraction factors for each HIGH-COMBI demonstration plant are presented in Table 3. Based on these monitoring data the simulation and design tools were validated and the performance of the plants evaluated. In order to derive common energy figures for all the installations, the monitoring procedure developed in IEA SHC Task 38 Subtask A and B has been used as assessment tool [35].

In the present section of the paper a technical description for each plant is given, together with representative energy performance figures derived from the application of the monitoring procedure—where available.

4.1. The Greek demonstration plant

The Greek plant is installed in an existing office building, at the site of the Centre for Renewable Energy Sources and Saving - CRES in Athens (latitude 38°00′N & longitude 23°55′ E), Greece. The building covers a total of 427 m^2 with a volume of 1296 m^3, which is typical of medium sized offices and multifamily buildings. The building was constructed in 2000 and was initially designated as laboratory. In 2008, the building was renovated and it is currently used as office.

The Greek plant operates since December 2011. The main system components of the plant include: selective flat plate solar thermal collectors, a seasonal underground thermal energy storage, an absorption chiller, a wet cooling tower and an energy efficient heat pump (HP).

In heating operation mode as shown in Fig. 1, the solar system is designed to supply the building with a hot water temperature of 45 °C. Priority is given to the heat coming directly from the solar field or/and the UTES. The HP is connected in series and operates as a backup, using the UTES as a heat source, increasing the supply

Table 1
General characteristics of each HIGH-COMBI demonstration plant.

Country **Location**	**Greece** Athens	**Italy** Milano	**Spain** Barcelona	**Austria I** Gleisdorf	**Austria II** Gleisdorf	**Austria III** Graz
Operation	December 2011	July 2011	December 2011	July 2008	July 2010	July 2008
End user	Office	Sport facilities	Health care and social housing for elderly people	Town hall offices	Offices	Offices
Conditioned area	427 m^2	700 m^2	3700 m^2	2533 m^2	1000 m^2	430 m^2
Heat/cold distribution system	Fan coils	Fan coils, air handling unit	Radiant floor	Radiators, floor heating, ceiling elements, fan coils	Ceiling elements, radiators	Radiators, ceiling elements
Heating requirements	12.3 MWh/a	59 MWh/a	12 MWh/a	142 MWh/a	14.7 MWh/a	38 MWh/a
Cooling requirements	19.4 MWh/a	23 MWh/a	60 MWh/a	71 MWh/a	14.8 MWh/a	11 MWh/a

Table 2
Solar thermal collectors and solar cooling technical characteristics of each HIGH-COMBI demonstration plant.

Country	**Greece**	**Italy**	**Spain**	**Austria I**	**Austria II**	**Austria III**
Solar thermal collectors						
TECHNOLOGY	Selective flat plate	Selective flat plate	Evacuated heat pipe tubes	Flat plate collectors HT	Flat plate collectors HT	Flat plate collectors HT
Area (gross)	149.5 m^2	146 m^2	200 m^2	302 m^2	64 m^2	59 m^2
Heat storage	58 m^3	22 m^3	9 m^3	4.6 m^3	10 m^3	2 m^3
Solar cooling						
Technology	Absorption chiller	Absorption chiller	Absorption chiller	Absorption chiller & solar ACM (Silica gel)	Absorption chiller	Absorption chiller
Nominal capacity	35 kW	35 kW	70 kW	35 kW	19 kW	17.5 kW
Cold storage	Not applicable	4 m^3	1 m^3	1 m^3	Not Applicable	0.2 m^3
Auxiliary system	Heat pumps	Heat pumps	Condensing gas boilers/ compression chillers	District heating (natural gas)	Vegetable oil driven CHP, natural gas boiler, ground source heat pump	District heating

Table 3
Solar fraction of each HIGH-COMBI demonstration plant.

Country	**Greece**	**Italy**	**Spain**	**Austria I**	**Austria II**	**Austria III**
Solar fraction (SF)						
Designed SF	85%	54%	54% (overall), 68% (only social housing)	36%	66%	100% solar cooling fraction
Measured SF	70%	Not available (no real load as the building is not yet in use)	Not available	25%	13%	43%
Reason of discrepancies between designed and measured SF	The operation period of the plant (December 2011–February 2012) was not indicative for the expected annual SF	–	–	Although the measured solar gain was higher than the simulated one, the measured SF was less than the designed because: (a) The measured Heat Demand for heating and cooling was 37% higher than the simulated one and (b) the lower than expected measured coefficient of performance (COP) of the desiccant evaporative cooling (DEC) system	The much higher monitored heat demand than the simulated one (11 times more), because other heat demands of the building, via a district heating network, are covered in reality	The design of the plant was focused on 100 % solar cooling, so it was not designed for a specific solar heating fraction

temperature to the building, if necessary. Depending on the building's heating demand, the availability of solar radiation and the water temperature inside the UTES, a control system selects the optimum heat source or a combination there after.

The possible operating modes for winter period are: (1) Solar collectors; (2) Underground seasonal thermal energy water storage (UTES); (3) Solar collectors—heat pump; (4) UTES—heat pump.

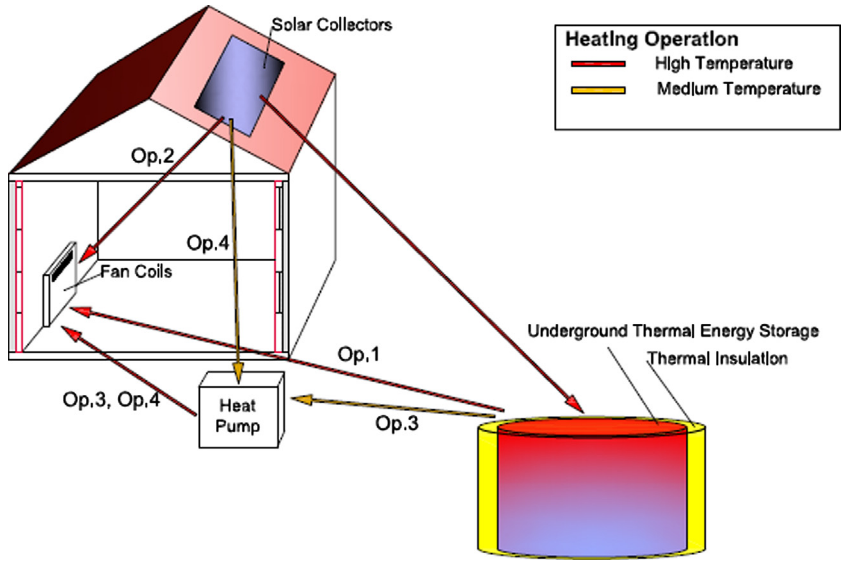

Fig. 1. Energy flow scheme of heating operations of the Greek plant.

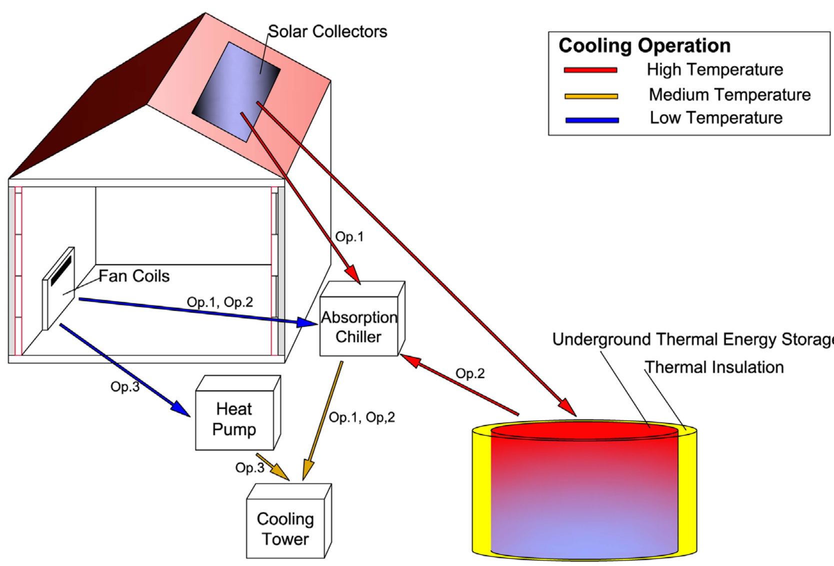

Fig. 2. Energy flow scheme of cooling operations of the Greek plant.

In cooling operation, as illustrated in Fig. 2, the solar system is designed to supply the building with a chilled water temperature of 7 °C. Priority is given to the absorption chiller due to its low electrical energy consumption. The HP is connected in series and operates as a backup energy source, reducing the supply temperature to the building, if necessary. The absorption chiller is driven by either the heat output from the solar collectors at a "high" temperature usually in the range of 70–85 °C or the UTES and provides useful cooling by extracting heat from the building. During summer, whenever there is excess solar energy (i.e., low cooling load or SHW demand), it is delivered directly to the UTES. The water in the tank may be heated up to about 90 °C in summer. Depending on the building's cooling demand, the availability of solar radiation and the water temperature inside the UTES, a control system selects the optimum heat source or a combination there after.

The possible operating modes for summer are: (1) Solar collectors—absorption chiller; (2) UTES—absorption chiller; (3) Solar collectors—absorption chiller & heat pump; (4) UTES—absorption chiller & heat pump.

During the intermediate seasons (autumn and spring operation), when heating and cooling loads are relatively low, the excess solar energy will be stored in the UTES, reaching a water temperature of about 95 °C.

The estimated solar fraction is around 85% of the total thermal energy requirement.

4.2. The Italian demonstration plant

The Italian plant is installed at the "Idroscalo"—HydroPark. The Hydroplane Port is located on the east side of Milan and is today surrounded by a park dedicated to recreational activities with approximately 2 million visitors per year. So far the building has not been in use for several years. After refurbishment it will serve activities of public interest, such as sport and other activities. The demonstration solar plant is covering heating, cooling and SHW loads.

The Italian plant is in operation since July, 2011. The system combines solar cooling with heat pumps, which is a very promising trend of research and commercial applications. It is a complete

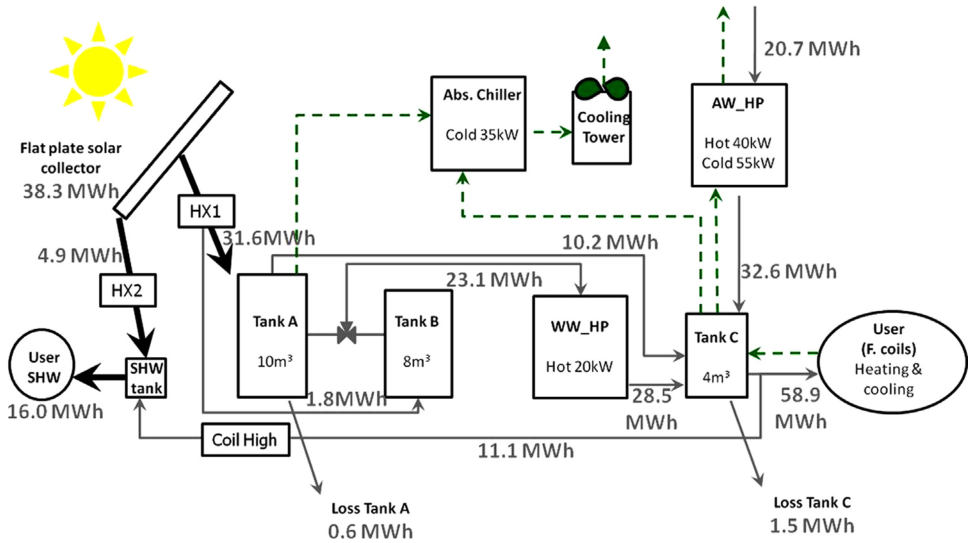

Fig. 3. Energy flow scheme in winter mode of the Italian plant.

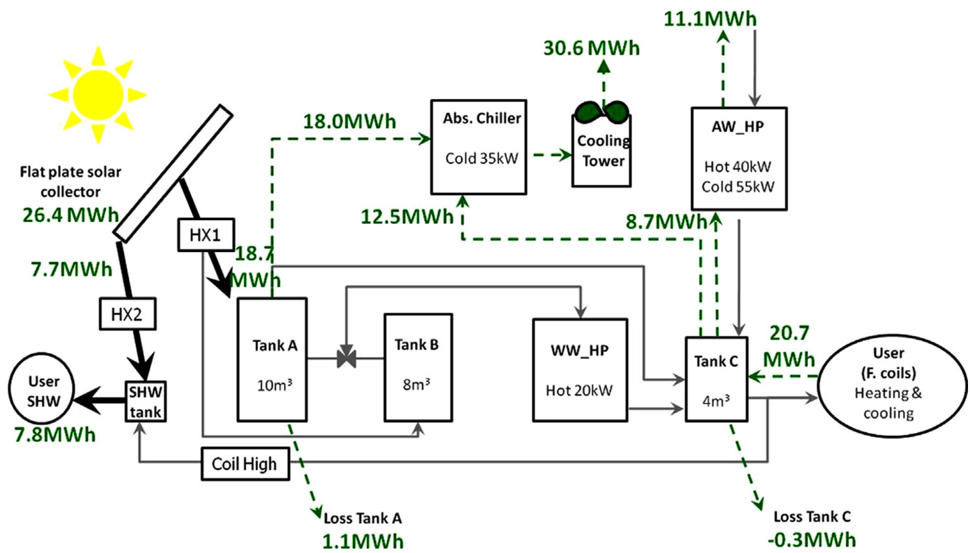

Fig. 4. Energy flow scheme in summer mode of the Italian plant.

combination, since the water–water heat pump uses in winter hot water from the solar tank as cold source, adding energy from the electricity network in order to reach the desired temperatures. A second heat pump (air–water) is used to cover the peak loads in winter, as well as in summer.

A water–water heat-pump is connected "in series" with the solar tank and is in charge of covering heat demand in case solar energy is not available. This increases both the solar plant efficiency and the heat pump's COP.

There are two operation modes available: the winter and summer operation. Figs. 3 and 4 show the energy flow scheme of the system in summer and winter respectively. In winter operation, the solar thermal system heats up the SHW storage and the two storages tanks: tank A and tank B. Priority is given to the SHW tank. Hot water from tank A can charge the buffer storage tank C. Tank C can be also charged by the water to water heat pump that is extracting heat either from tank B or from both tanks A and B. Tank C is maintained at about 40–45 °C, in order to activate fan-coils (40 °C) and air handling unit (AHU). If necessary, an air to water heat pump charges tank C. The auxiliary heat for the SHW (when the solar heat is not enough) is provided by tank C.

In summer operation, the solar thermal system heats up the SHW storage and the two tanks A and B. Priority is given to the SHW tank. Then tank A is heated up till the maximum accepted temperature is reached (90 °C). Tank A delivers heat to the absorption chiller, which produces cold water to be stored in the tank C; therefore it is used in summer as a cold storage. Heat from absorption chiller is rejected toward the environment by means of an incorporated cooling tower. The water–water HP (WW_HP) is shut down in summer. Cold backup is therefore provided by the air–water HP (AW_HP), which directly cools down tank C. Fan-coils and AHU work at a delivery temperature of 8 °C. The auxiliary heat for the SHW (in the very rare cases when the solar heat is not enough) is provided by an electric resistance. Estimated solar fraction is around 55% of total load.

4.3. The Spanish demonstration plant

The Spanish plant is installed at a newly designed building, in the center of Barcelona. The building, owned by the Patronat Municipal de l'Habitage de Barcelona, comprehends a healthcare center in the three lower floors, and 32 social housing flats for elderly people in the upper floors. The building has been designed

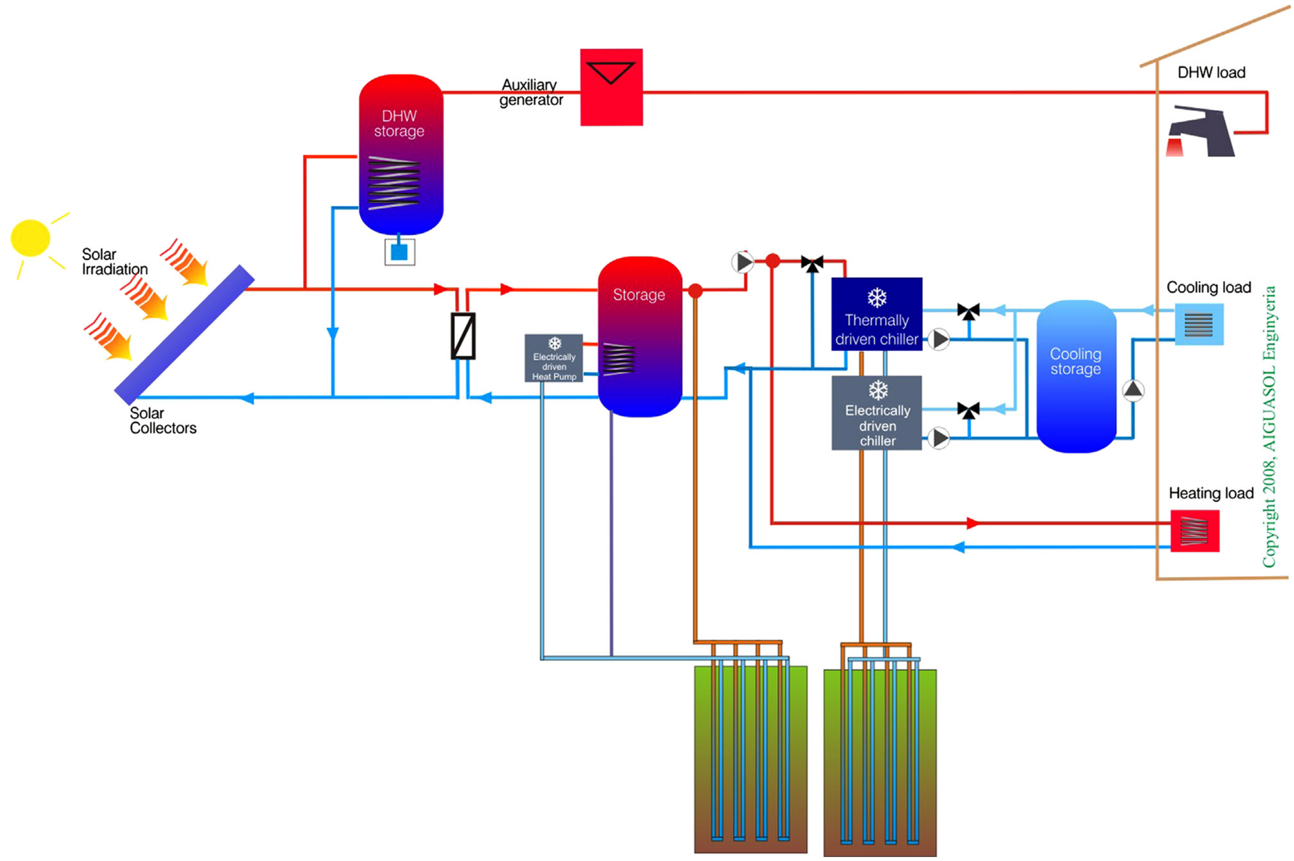

Fig. 5. Energy flow scheme of the Spanish plant.

and built according various energy optimization criteria, through the detailed simulation and the proposal of different measures (including the optimal size of insulation, the glasses to be used and the size of the balconies).

The installed system consists of 200 m^2 heat pipe evacuated tube collectors, a stratified storage tank, an absorption chiller, a compression chiller and a condensation boiler. The option to install geothermal heat exchangers was disregarded, due to substantially higher investment costs that could not be justified when energy price is taken in account. Additionally, the heat demand in winter is low and could be easily covered by the solar collectors.

The optimization process led to an optimal driving temperature for the absorption chiller (75–80 °C), for the optimal solar collectors inclination (25°) and for the specific heat storage ratio (35 l/m^2).

The main components of the Spanish demonstration plant are the evacuated heat pipe tubes, the absorption chiller of nominal capacity 70 kW_c, and wet cooling tower. The building has implemented with radiant floor for heating and cooling and a dehumidification has also been installed.

In Fig. 5 the energy flow scheme of the plan is given.

4.4. The 1st Austrian demonstration plant

Within the framework of the renovation of the old Town Hall (1321 m^2) and the construction of a new Service Centre (office building with 1212 m^2), a solar combi plus installation was realised in 2008. The system provides both buildings with heating and cooling energy as well as domestic hot water.

In Fig. 6 the energy flow scheme of the system is shown. Space heating energy is taken out of the central heat storage and is distributed via radiators and floor heating in the Town Hall and via ceiling elements and the heated supply air of the air handling unit in the Service Center. Domestic hot water is prepared with a “fresh water station” by the means of an external plate heat exchanger.

Space cooling energy is generated by the means of two different solar thermal cooling technologies—at the one side by an absorption cooling machine (ACM) and on the other side by a desiccant evaporative cooling device (DEC). The DEC is conditioning the hygienic air flow within the Service Center and the ACM covers the cooling load of both buildings. Cooling energy distribution occurs with fan coils in the Town Hall and with chilled ceilings in the Service Center.

Two different oriented collector fields are integrated in the system. One field is situated at the roof of the Service Center and the other one is situated on four so called “solar trees”. The generated heat is stored in one heat storage via an external plate heat exchanger and a stratifier unit. A district heating access serves as heat-backup.

4.5. The 2nd Austrian demonstration plant

The 1000 m^2 office building of the Feistritzwerke STEWEAG GmbH (a regional energy and municipal water supplier) is located in Gleisdorf and was equipped with a solar thermal heating and cooling system in June 2010. Air ventilation is provided via manual window openings. Solar thermal energy is produced by a 64 m^2 collector field and is stored in five 2 m^3 heat storage tanks. One of these tanks is equipped with a stratifier unit and is switched in series to the other four tanks. That high temperature tank can be operated independently of the other four tanks.

Space heating occurs with the ceiling elements and with the existing radiators. In Fig. 7 the energy flow scheme of the system is shown. During the heating season two vegetable oil and one natural gas driven combined heat and power plant (CHP), a

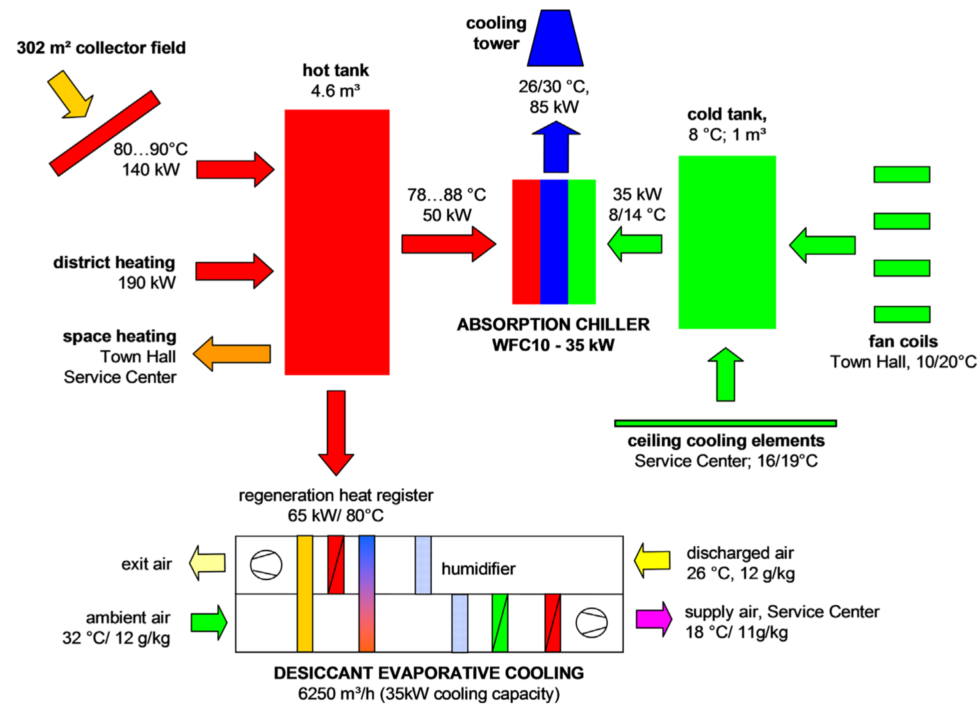

Fig. 6. Energy flow scheme of the solar heating and cooling system of the 1st Austrian Plant.

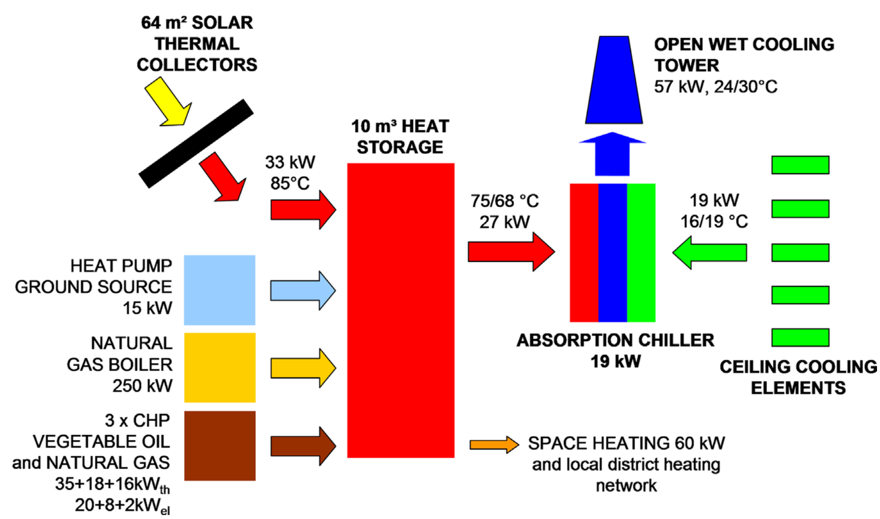

Fig. 7. Energy flow scheme of the 2nd Austrian Plant.

condensing natural gas boiler and a ground source heat pump serve as backup. During the cooling period cold water is mainly generated with solar thermal energy and waste heat from the vegetable oil driven CHPs. An absorption chiller is driven with heat from the storage. The produced cold water is transported directly to the cold distribution system without any cold water storage in between in order to avoid an extra circulating pump. The office rooms are cooled and heated via suspended ceiling elements made of plaster boards with integrated cold water pipes.

The system concept is based on a dynamic control strategy of the absorption chiller. The cooling capacity of the chiller is controlled at the level of the actual required cooling load of the building. This is realised by controlling the flow rates and the temperatures of the chiller's periphery cycles as well as the speed of the cooling tower fan. Heat rejection is realised with a wet, open cooling tower combined with an electrolytic water preparation device with the advantage of reduced electricity consumption. With that strategy a cold water storage and a second cold water pump got unnecessary, with the advantage of less energy consumption for the cold water production.

4.6. The 3rd Austrian demonstration plant

The office building of SOLID was renovated in 2004 and the solar heating and cooling system was installed in 2008. The office facade has a south and west orientation. To reduce the solar gains external shading devices are installed at each glazing. Because of internal gains and ventilation via windows, active cooling is indispensable. The solar cooling equipment is installed in a so-called “Cooling Cabin” placed under a pergola which is situated in front of the office building as a nice main entrance. The solar collectors are installed on the roof of this pergola. The hybrid cooling tower is placed on the flat roof of the office building.

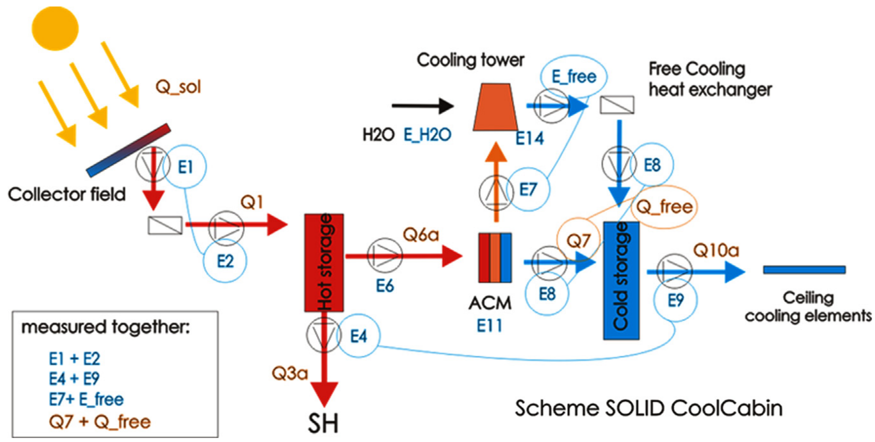

Fig. 8. Energy flow scheme of the 3rd Austrian Plant.

The cooling load of the office rooms is taken out via ceiling cooling elements.

In Fig. 8, the energy flow scheme of the system is shown. A closed absorption cycle for generating cooling energy is employed. Autonomously solar thermal generated heat by high temperature flat plate collectors is used to regenerate the process. Within the absorption cooling machine water is used as refrigerant and lithium bromide is used as solvent. The cold water generated by the absorption cooling machine is used to cover internal and external heat gains and also the heat income caused by window-ventilation in the office rooms. In winter the solar collectors are in assistance to the space heating. In summer and winter the solar generated heat is stored in one buffer storage and all energy demand is taken out of it. The additional heat from the district heating is not stored in the tank but directly carried to the space heating system. A special application is the usage of the hybrid cooling tower for direct cooling via the ceiling cooling elements.

5. HIGH-COMBI software tool: “TRNSED”

A user friendly software tool was developed in the framework of HIGH-COMBI project, showing the potential of solar thermal energy to cover a high fraction of the heating, cooling and SHW consumption of buildings. The objective of the software program is to contribute in the optimum system's operation and to allow basic dimensioning and economic analysis for planners.

Three main system concepts had been used as available scenarios in TRNSED:

- a “solar combi plus” system,
- a high “solar combi plus” system with seasonal storage through borehole thermal energy storage, and
- a high “solar combi plus” system with seasonal underground water thermal energy storage.

The software includes an overall energy analysis of each component, input and output of the system in a visualized user friendly way, cost analysis, comparison of the solar plant with a reference one (gas boiler and electric chiller). The results of the simulation present the economic, energy and environmental analysis. In the economic analysis of the software tool, it is possible to estimate the necessary subsidy needed to make the investment sustainable.

The software menu consists of five display sheets with different information included, according to particular configuration for each country's plant. The software tool is available on-line at the project website.

6. Conclusions

“High solar combi plus” systems that combine solar heating and cooling technology in collaboration with thermal storage usage, seems to be an ideal solution, extending the use of the solar system throughout the year. Although a limited number of applications have been realized, on-going research and demonstration efforts are striving to achieve high solar fractions, thus enabling future market growth. “High solar combi plus” systems may play an integral role in the near future and support European and national efforts to meet the ambitious energy saving targets.

As the high initial cost deter the application of “solar combi plus” systems, in almost all EU countries are considering special support programmes and stimulation schemes for a larger market deployment of solar thermal technologies. Such installations when supported by substantial investment funds can overcome the existing cost barriers and prove high quality performance and a high level of reliability. On the other hand, in some other countries the support programmes are frequently changing because of short-term political decisions.

The following aspects have been identified in order to further investigate the concept presented in the current work:

- Use of ground heat exchangers around the STES.
- Use of low cost thermal insulation materials.
- Use of an adsorption heat pump as the auxiliary heating and cooling source. This combination may lead to a 100% renewable energy coverage of the heating/cooling demands with a smaller and cheaper plant.
- Examination of similar systems in other countries.
- Optimization procedure with even more variables such as the control system, the solar collectors and STES combined with GHE.

Acknowledgments

The HIGH-COMBI project was conducted as part of the EU Sixth Framework Programme (Contract no: TREN/07/FP6EN/S07.68923/038659) and was partly financed by European Commission under the co-ordination of Centre for Renewable Energy Sources and Saving (CRES).

The project had duration of 4.5 years from June 2007 to December 2011. The consortium of the project consisted of 12 partners from 6 countries (Greece, Austria, Italy, Germany, Spain and Romania).

CRES would like to thank the project partners: AEE INTEC (Institute for Sustainable Technologies, Austria), AIGUASOL (Sistemes Avançats d'energia solar termica, Spain), FRAUNHOFER-ISE (Fraunhofer-Institut Solare Energiesysteme, Germany), NOA (National Observatory of Athens, Greece), PMHB (Patronat Municipal de l'Habitatge, Ajuntament de Barcelona, Spain), POLIMI (Politecnico di Milano, Italy), Provincia di Milano, Italy, S.O.L.I.D. (Solarinstallation und design GmbH, Austria), SOLE SA, Greece, SOLITES, (Steinbeis Innovation GmbH, Germany), UOR (University of Oradea, Romania).

HIGH-COMBI website is available at ⟨www.highcombi.eu⟩.

This project is dedicated to the memory of Dr. Tomas Núñez (1965–2011) from Fraunhofer ISE, member of the HIGH-COMBI team and a leading expert on solar cooling.

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